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AIRFRAME ARCHITECTURE AND DESIGN OF THE SWIFT-UAV: AN OPEN-SOURCE 20 KG-CLASS 3D-PRINTED FIXED-WING RESEARCH PLATFORM

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ABSTRACT

Instrumented aerial platforms play an important role in scientific data collection, flight testing, and the development of mission-specific airborne research systems. However, fixed-wing UAV platforms capable of carrying heavy scientific payloads over extended durations are often costly, proprietary, or difficult to fabricate and modify, limiting their accessibility to smaller research groups, student teams, and low-resource development efforts. SWIFT-UAV (Scientific Workhorse for In-Flight Testing) is an open-source fixed-wing UAV developed to address this need through low-cost construction, straightforward assembly, and consumer-accessible manufacturing methods. The platform is constructed primarily from widely available 20×20 mm extruded aluminum profiles and PLA components printable on a standard 256 mm build plate, and it uses off-the-shelf avionics to reduce fabrication complexity and improve reproducibility. The design targets an approximate build cost below $2,000, a nominal 5 kg payload capacity, a 15 kg estimated takeoff weight, a 20 kg maximum takeoff weight (MTOW), a 25 m/s cruise speed, and a nominal endurance of one hour using a 10 Ah battery. The vehicle emphasizes modularity and repairability to support payload integration, rapid field maintenance, and iterative testing, while maintaining practical flight capability for research use. The resulting platform is intended to provide a reproducible and adaptable baseline for experimental payload development, subsystem evaluation, and future flight research activities.

1 Introduction

Unmanned aerial vehicles (UAVs) have become increasingly important tools for scientific data collection, instrumented flight testing, environmental monitoring, and the development of mission-specific airborne systems [1]. Fixed-wing platforms are particularly attractive in these roles because they can support longer-duration missions and greater operational range than many multirotor alternatives, making them well suited for persistent sensing and large-area survey missions where endurance and energy efficiency are important design considerations. Despite this utility, access to suitable fixed-wing research platforms remains limited. Systems capable of carrying scientific payloads for extended operations are often expensive, proprietary, or difficult to fabricate, modify, and repair, creating a barrier for smaller research groups, student teams, and laboratories operating without specialized manufacturing resources.

Accessible fixed-wing UAV platforms for research remain limited, even though a growing number of UAV systems are available to researchers and hobbyists. Commercial solutions may offer capable and integrated airframes, but proprietary designs can restrict modification, complicate payload integration, and limit transparency in system architecture.

Several open-source and research-oriented UAV platforms have been developed to improve accessibility and adaptability for academic and experimental use. Sonkar et al. [2] developed a low-cost composite hybrid VTOL UAV platform that demonstrates how relatively simple manufacturing approaches can support experimental aerial systems. El Adawy et al. [3] presented the design and fabrication of a fixed-wing UAV platform using conventional structural design methods suitable for laboratory-scale development and experimental validation. These efforts illustrate how research-oriented UAV platforms can be designed to support modular architectures, open documentation, and integration of experimental subsystems while remaining feasible for university laboratories and small research teams.

Despite these developments, practical barriers to adoption remain. Research-oriented UAV designs often rely on specialized fabrication processes, large-format manufacturing equipment, composite structures, or labor-intensive assembly methods that limit accessibility and reproducibility. Designing UAV systems around standardized industrial components and commonly available manufacturing tools can improve robustness, simplify assembly, and enable platforms to be reproduced more easily across multiple research groups [4]. Engineering design methodologies emphasizing modularity, standardized interfaces, and design-for-manufacture principles are widely recognized approaches for improving system accessibility and maintainability. Applying these principles to UAV development enables airframes to be constructed from repeatable subassemblies and commercially available structural members, improving repairability while reducing fabrication complexity.

Comparable fixed-wing and hybrid research UAV development efforts frequently emphasize manufacturability, modularity, and repeatable validation workflows. For example, Sonkar et al. [2] demonstrate a composite hybrid VTOL configuration intended for low-cost experimental development, while El Adawy et al. [3] focus on the structural design and fabrication workflow of a conventional fixed-wing UAV platform. At the commercial end of the spectrum, system-integrator platforms such as the UAV Factory Penguin B provide a reference point for payload-oriented fixed-wing UAV packaging and modular access features, but at substantially higher system complexity and cost than the objective of this work [5].

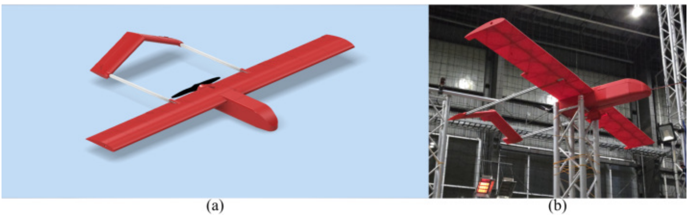
Within operational and regulatory contexts, UAV platforms of this approximate scale are often described using the U.S. Department of Defense (DoD) unmanned aircraft system grouping framework. In this classification scheme, Group 2 UAVs typically operate below 3,500 ft above ground level and have a maximum gross takeoff weight up to approximately 55 lb (25 kg) [6]. This category provides a useful reference point for situating medium-scale research UAV platforms such as the system developed in this work.

SWIFT-UAV (Scientific Workhorse for In-Flight Testing) was developed to address this gap as an accessible fixed-wing platform for aerial scientific research [7]. The platform prioritizes low-cost construction and straightforward assembly while retaining the payload capability and endurance needed for practical research missions. SWIFT-UAV is designed to function both as a complete UAV system for aerial testing and as a baseline platform for the development and evaluation of parallel technologies, including (1) structural batteries [8], (2) studies on the effects of fast charging and optimal charging strategies on battery degradation in autonomous short-haul fixed-wing transportation [9], and (3) power-system digital twin development.

Figure 1 provides an overview of the system: Fig. 1(a) shows the CAD model of the full airframe with the propeller visible, and Fig. 1(b) shows the current prototype on a test stand. These views highlight the airframe architecture and the intended emphasis on modular subassemblies and standardized structural members.

The contribution of this work lies in the development of an integrated, open-source UAV platform intended to be reproducible using consumer-accessible fabrication tools. This paper describes the design requirements that shaped the platform, the major vehicle and subsystem design decisions, and the manufacturing and assembly approach used to support low-cost construction and modular replacement of damage-prone components. It also summarizes the current implementation of the system and its preliminary ground-based validation through integrated iron-bird testing.

The remainder of this paper is organized as follows. Section 2 summarizes the design requirements and system targets for the SWIFT-UAV platform. Section 3 describes the methodology used to develop the airframe architecture and subsystem integration approach. Section 4 presents the vehicle design, including



(a) (b)

FIGURE 1. Overview of the SWIFT-UAV airframe architecture: (a) CAD model with propeller shown and (b) prototype on test stand.

the aerodynamic sizing, structural layout, flight-control architecture, propulsion system, and battery integration. Section 5 describes the design-for-manufacture and assembly strategy. Section 6 concludes the paper and summarizes planned future validation activities.

2 Design Requirements and System Targets

SWIFT-UAV was developed as a fixed-wing platform for aerial scientific research with requirements shaped by both flight capability and practical build constraints. The objective was not to optimize a single performance metric, but to define a set of targets that yield a usable research aircraft while remaining reproducible with commonly available materials and tools.

Affordability was a primary requirement, with a target build cost below $2,000 while supporting a nominal 5 kg payload. A second requirement was manufacturability using consumer-scale additive manufacturing; printed components were constrained to a standard 256 mm build volume, which motivated segmentation of large components such as the wing shells and fuselage sections. A third requirement was structural simplicity and serviceability, achieved by using standardized 20×20 mm extruded aluminum profiles as primary load paths and reserving printed PLA parts for aerodynamic shells, interfaces, and integration features.

In addition to these build-driven constraints, the platform targets a nominal operating weight of approximately 15 kg and a maximum takeoff weight (MTOW) of 20 kg. A nominal cruise speed of 25 m/s and a nominal endurance of approximately one hour using a 10 Ah battery were selected as representative operating targets. The wing was sized to support the 20 kg maximum takeoff condition. The primary requirements can be summarized as follows:

- provide an open-source fixed-wing UAV architecture for aerial scientific research and in-flight testing;
- support a nominal payload capacity of 5 kg while remaining within a 20 kg MTOW;
- use low-cost, commercially available structural members, hardware, propulsion components, and avionics where practical;
- enable fabrication using consumer-scale 3D printers with a 256 mm build-plate constraint;
- support modular replacement of damage-prone airframe sections to simplify field repair and iterative development;
- retain sufficient endurance and payload flexibility for experimental subsystem and payload integration.

The principal design requirements and targets are summarized in Table 1.

TABLE 1. SWIFT-UAV design requirements and target specifications.

Category	Requirement / Target
Platform type	Open-source fixed-wing UAV
Primary application	Aerial scientific research / in-flight testing
Cost target	Below $2,000 for the baseline system, excluding mission-specific research payloads
Payload target	5 kg nominal
Nominal operating weight	15 kg
Maximum takeoff weight	20 kg MTOW
Nominal cruise speed	25 m/s
Nominal endurance	Approximately 1 h
Wing sizing condition	20 kg maximum takeoff condition
Manufacturing constraint	Printable on a standard 256 mm build plate
Structural materials	20×20 mm extruded aluminum profiles and PLA components
Integration philosophy	Off-the-shelf avionics
Assembly objective	Minimal hardware and adhesive use
Design priority	Accessibility, manufacturability, modularity, and repairability

3 Methodology Overview

The SWIFT-UAV was developed using a requirements-driven design process intended to balance flight performance, manufacturability, cost, and modularity. First, mission-level requirements were established for payload capacity, MTOW, endurance, cruise speed, build cost, and fabrication accessibility. Second, preliminary aerodynamic sizing was performed using classical fixed-wing lift relations to estimate the wing area and flight speed required to support the design weight. Third, the airframe was modeled in CAD to package the wing, fuselage, tail-boom structure, payload bay, propulsion system, battery, and avionics within a modular architecture. Fourth, the major structural load paths were assigned to commercially available extruded aluminum profiles, while 3D-printed PLA components were used for aerodynamic shaping, subsystem interfaces, and replaceable airframe sections. Finally, the resulting prototype was assembled and evaluated through integration checks and ground-based subsystem testing to assess accessibility, packaging, and suitability for future flight validation.

The computational and analytical results presented in this work are used as preliminary design estimates rather than final validated performance data. Detailed aerodynamic validation, structural finite element analysis, propulsion bench characterization, and flight-test-based model refinement are planned as future work once the prototype completes progressive ground and flight testing.

4 Vehicle Design

The vehicle design of SWIFT-UAV balances aerodynamic utility and structural simplicity with fabrication constraints imposed by consumer-scale printing and widely available structural members. This section outlines the principal aerodynamic, structural, and propulsion sizing decisions that shape the current configuration.

4.1 Aerodynamic Design

The aerodynamic design of SWIFT-UAV was driven by the requirement to support a maximum takeoff weight of 20 kg while maintaining a simple wing geometry that can be segmented for fabrication. A wingspan of 2.6 m was selected together with a nominal chord of 0.33 m, with the chord scale influenced in part by the need to segment wing components for fabrication on a standard 256 mm build plate. The resulting wing has an aspect ratio of approximately 8.4. The principal aerodynamic design parameters are summarized in Table 2.

The NACA 4415 airfoil was selected because its thickness accommodates internal structural components while also providing relatively high lift and gentle stall characteristics. In addition, aerodynamic performance data for the NACA 4415 family of sections are widely available in published literature and standard airfoil databases, simplifying preliminary sizing and analysis [10, 11].

Initial wing sizing was performed using the standard lift relation

$$L = \frac{1}{2}\rho V^2 S C_{\mathrm{L}} \tag{1}$$

where L is the generated lift, ρ is the air density, V is the flight speed, S is the wing planform area, and C_{L} is the lift coefficient. The requirement for steady level flight was taken as

$$L = W. \tag{2}$$

In Eq. (2), W is the aircraft weight at the selected design condition. For the present sizing case, W corresponds to the 20 kg MTOW, or approximately 196 N. These relations were used to size the wing for the maximum takeoff condition and estimate the flight speed required to support the design weight. Computational fluid dynamics (CFD) was then used to verify the classical sizing results and to estimate drag at the design point. For the final wing geometry, the CFD results indicated that a flight speed of approximately 30 m/s was required to generate a total lift of about 200 N, corresponding to the 20 kg maximum takeoff condition. At this operating point, the predicted drag was approximately 21.6 N, giving a lift-to-drag ratio of about 9.1.

4.2 Structural Design

The structural architecture uses extruded aluminum profiles as primary load paths, while 3D-printed PLA parts provide aerodynamic shape and local interfaces. This approach reduces the amount of printed material required in highly loaded regions and

TABLE 2. Summary of principal aerodynamic design parameters and CFD results for SWIFT-UAV.

Parameter	Value
Airfoil	NACA 4415
Wingspan	2.6 m
Nominal chord	0.33 m
Aspect ratio	8.4
Design maximum takeoff weight	20 kg MTOW
Design lift condition	200 N
Required flight speed at design lift	30 m/s
Predicted drag at design lift	21.6 N
Lift-to-drag ratio	9.1

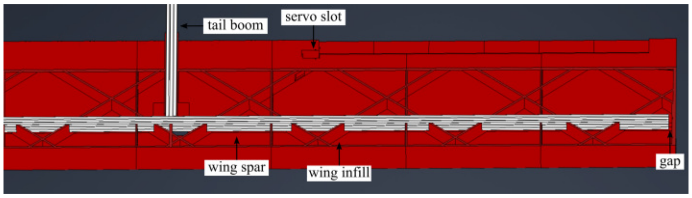


FIGURE 2. Cross-sectional view of the wing showing the extruded aluminum wing spar, thin-walled printed shell, and internal lattice structure used.

allows standardized metallic members to carry the majority of bending loads.

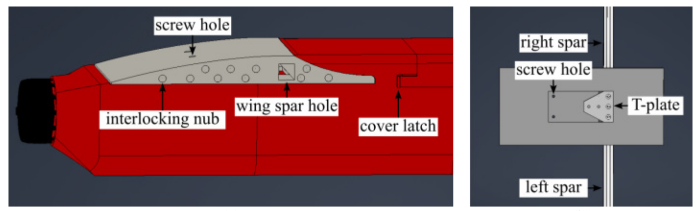
A twin-boom configuration was selected to provide a simple and accessible structural path from the wing to the empennage while preserving a central region for the fuselage, payload, propulsion integration, and battery placement. The twin-boom layout also allows the tail assembly to be connected directly to the wing structure using standardized aluminum members, reducing the need for large printed load-bearing components and improving modularity during assembly and repair.

Within the wing, the primary structural members are an extruded aluminum wing spar and an extruded aluminum tail boom extending rearward from the wing box into the empennage. The surrounding wing shells are thin-walled 3D prints with an internal cross-lattice structure that interfaces directly with these aluminum members. A cross-sectional view of the wing architecture is shown in Fig. 2. As shown in Fig. 2, the spar is embedded within the printed wing shell, and the lattice structure provides load transfer and local stiffness while maintaining a thin aerodynamic skin.

Because the wing is manufactured in multiple sections, torsional shear flow is not carried continuously through a single uninterrupted wing skin as it would be in a conventional one-piece wing. To address this, each wing segment includes a male-female interlocking feature that mates with the adjacent segment. A compression screw at the outboard end of the assembly pulls the stack of wing sections together by reacting against the final wing section while the wing spar terminates short of the outermost end. This arrangement compresses the assembled wing sections into a unified structure and improves load transfer across the segmented wing.

The fuselage is likewise divided into printed sections sized for fabrication on a standard 256 mm build plate. These sections are bonded together to form the full fuselage, reflecting the expectation that the fuselage will remain a largely permanent assembly. Internal geometry was also designed to support subsystem integration, including provisions for servo routing to the aluminum members and the use of the profile slot as a protected path for wiring. In contrast to the fuselage, the wing sections are not permanently bonded, since they are more likely to experience damage and are intended to be quickly replaceable.

An additional extruded aluminum profile is integrated into the lower fuselage, where it serves two structural roles. First, it provides a hard point for externally mounted payloads. Second, it acts as a load-carrying member for the forward landing gear. The wing structure ties into the fuselage through a dedicated wing box, which slots into the fuselage through a tongue-and-groove system and is retained using only two screws. A cross-sectional view of the wing box and fuselage interface is shown in Fig. 3. Figure 3(a) shows the cross-sectional interface, and Fig. 3(b) shows the bottom-up view of the wing box coupling to the spars.



(a) (b)

FIGURE 3. CAD views of the UAV: (a) cross-sectional view of the wing box and fuselage interface and (b) bottom-up view of the wing box coupling to the spars.

4.3 Control Surfaces, Tail Section, and System Integration

SWIFT-UAV uses a conventional fixed-wing control architecture. Roll control is provided by wing-mounted ailerons, pitch control is provided by an elevator on the horizontal tail, and yaw control is provided by rudder surfaces on the vertical stabilizers. These control surfaces are actuated using standard servo mechanisms, with wiring routed through protected internal paths and along the aluminum profile slots where practical. The tail section is supported by the twin-boom structure, which maintains geometric alignment between the wing and empennage while allowing the tail assembly to be removed or modified separately from the central fuselage.

Motor control is provided through an electronic speed controller connected to the onboard avionics system. The platform is intended to be compatible with commonly used fixed-wing autopilot hardware, allowing researchers to implement manual, assisted, or autonomous control modes depending on the experimental objective. The battery is placed within the central fuselage region so that its location can be used to help set the aircraft center of gravity while preserving accessibility for installation, inspection, and replacement. This central placement also leaves the lower fuselage rail available for payload attachment and landing-gear load transfer.

4.4 Propulsion and Battery Sizing

The propulsion system was sized to satisfy the endurance requirement while retaining substantial thrust margin. A MAD X7215 motor was selected to provide a maximum thrust-to-weight ratio of approximately 0.7 at the 20 kg maximum takeoff condition [12]. This thrust margin supports takeoff and climb performance while preserving flexibility for payload configurations beyond the nominal mission case. The motor, propeller, and battery combination was selected using manufacturer performance data and the estimated cruise drag so that the nominal cruise operating point remains well below the maximum thrust condition. The principal propulsion sizing parameters are summarized in Table 3.

For steady cruise, the required thrust was taken as equal to the aircraft drag,

$$T_{\text{cruise}} = D. \tag{3}$$

Using the aerodynamic analysis, the estimated cruise current draw was approximately 6 A. Endurance was estimated from the battery capacity and average current draw as

$$t = \frac{C}{I}, \tag{4}$$

where C is the battery capacity in ampere-hours and I is the average current draw. For a 12S 10 Ah battery, this gives an ideal cruise endurance of approximately 1.6 h. To account for the higher power demand during takeoff, climb, and maneuvering, an additional 20% energy margin was included in the sizing process. This reduces the effective endurance estimate to approximately 1.4–1.5 h, which still exceeds the nominal one-hour mission requirement. A 12S battery and 21 in propeller were selected because this operating point aligns with an efficient operating region of the MAD X7215 motor, allowing nominal cruise operation at relatively low throttle settings of approximately 30–40%.

TABLE 3. Summary of SWIFT-UAV propulsion sizing parameters.

Parameter	Value
Motor	MAD X7215
Battery	12S, 10 Ah
Propeller diameter	53.3 cm (21 in)
Maximum thrust-to-weight ratio	$\approx$ 0.7 at 20 kg MTOW
Estimated cruise current draw	6 A
Ideal cruise endurance	$\approx$ 1.67 h
Endurance with 20% margin	$\approx$ 1.4–1.5 h
Nominal cruise throttle	30–40%
Sizing priority	Endurance with thrust margin

5 Design for Manufacture and Assembly

A central objective of SWIFT-UAV was to support rapid assembly, disassembly, and transport without requiring specialized tools or destructive disassembly. In its current configuration, the aircraft can go from a flat-packed state to a fully assembled airframe in approximately 15 min, with a similar time required for disassembly. This short assembly cycle supports repeated transport and iterative testing, where setup time can otherwise become a practical bottleneck.

The assembly strategy follows directly from the structural architecture described previously. The wing is divided into modular sections that can be joined and removed without adhesive bonding, allowing damaged sections to be replaced individually rather than requiring repair of the full wing. By contrast, the fuselage is treated as a more permanent assembly and is printed in vertically segmented sections sized for a standard 256 mm build volume. These sections are bonded into a single body, while the wing box, tail boom, and other major interfaces are retained through direct mechanical attachment to the extruded aluminum structure.

This manufacturing strategy was selected to reduce the need for specialized fabrication equipment while preserving repeatability across different laboratories. Printed components are sized for consumer-grade printers, while the use of standardized aluminum profiles reduces dependence on custom composite tooling or large-format additive manufacturing. Dimensional tolerance management is handled through segmented printed interfaces, mechanical fastening, and localized fit-up features rather than through monolithic printed parts.

An exploded view of the major subassemblies is shown in Fig. 4. Figure 4(a) shows the segmented wing assembly prior to integration, and Fig. 4(b) shows the fuselage assembly. As shown in Fig. 4(a), individual wing sections can be transported separately, joined during assembly, and replaced independently if damaged. The fuselage segmentation shown in Fig. 4(b) enables fabrication on consumer-scale printers while producing a continuous final structure after bonding.

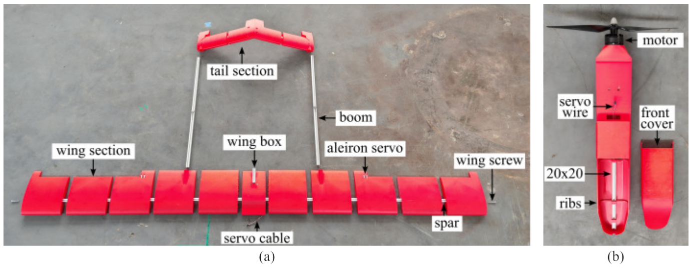


FIGURE 4. Exploded view of the UAV: (a) segmented wing assembly and (b) fuselage assembly.

When disassembled, the aircraft can be flat-packed into an approximately 1.5 m $\times$ 0.5 m footprint making the UAV easy to transport. The flat-packed configuration is shown in Fig. 5, which illustrates how the major subassemblies can be arranged for compact storage and transport.

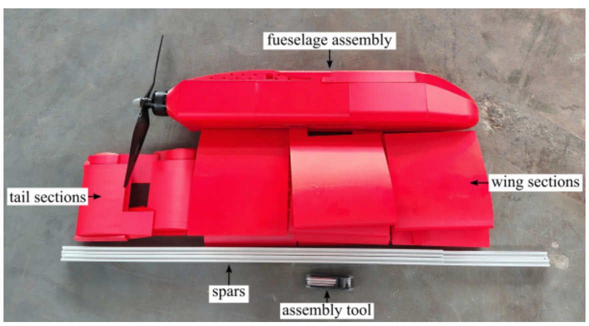


FIGURE 5. Flat-packed SWIFT-UAV configuration for transport.

6 Conclusion and Future Work

SWIFT-UAV was developed as an open-source fixed-wing platform for aerial scientific research, with the design targeting a combination of payload capability, endurance, and reproducible fabrication using consumer-accessible methods. The platform combines commercial extruded aluminum members with segmented PLA components printable on a 256 mm build plate, enabling modular replacement of damage-prone wing components and straightforward integration of payloads and avionics. The work presented here described the design requirements, aerodynamic sizing approach, structural architecture, propulsion sizing, and assembly strategy that together define the current system configuration.

The current prototype demonstrates the feasibility of a low-cost, modular, and reproducible fixed-wing research airframe built around consumer-accessible manufacturing methods and commercially available components. The design is intended to support future scientific payload integration, subsystem testing, and open-source replication by other research groups.

Future work will focus on progressive ground and flight testing. These trials will be used to validate the aerodynamic and propulsion sizing estimates, assess handling qualities and controllability, and evaluate payload and endurance performance under representative operating conditions. Additional work will include structural finite element analysis of the wing and tail-boom assemblies, propulsion bench testing, and refinement of the open-source documentation and bill of materials.

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